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AGARD ADVISORY REPORT No. 168

Range Instrumentation

The White Sands Missile Range Data Systems Manual

NORTH ATLANTIC TREATY ORGANIZATION

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RANGE INSTRUMENTATION

THE WHITE SANDS MISSILE RANGE DATA SYSTEMS MANUAL

Prepared by

L.R. Sugerman, Colonel, USAF (Ret.)
Physical Science Laboratory
New Mexico State University
Las Cruces, New Mexico 88003
USA

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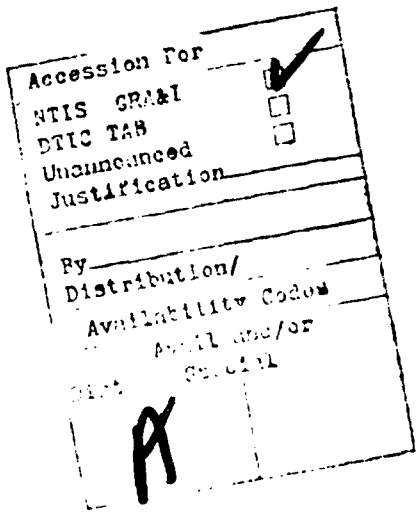
PREFACE

AGARD's Guidance and Control Panel considers the important, complex subject of Range Instrumentation within the technical scope of its activities. In addition to the isolated paper often presented at a conference, Lecture Series and Consultant Missions on related test and evaluation subjects have been sponsored or planned. Agardograph 219, "Range Instrumentation, Weapon Systems Testing and Related Techniques", published in February 1976 stands out as a major contribution to that category of literature.

As a service to NATO member countries who operate test ranges, may be considering the establishment of a range, or are just seeking capability information about the White Sands Missile Range, this GCP Advisory Report announces availability of a completely revised and updated ten-volume Data Systems Manual, in preparation since 1976.

Produced by the Physical Science Laboratory of New Mexico State University for the WSMR National Range Operations Directorate, the Data Systems Manual fills an urgent requirement for all those engaged in test range data collection, reduction, analysis and evaluation. In avoiding duplication of effort alone, the NATO community will find that it is a valuable, cost effective tool.

Requests for the document should be made through military channels directly to White Sands Missile Range.



INTRODUCTION

The White Sands Missile Range test complex is a unique combination of technology-based facilities available to support a wide range of research, development, test and evaluation programs for United States government agencies, commercial firms and qualified foreign governments. It is the largest and best instrumented overland test range in the free world, with 500 mile flight corridors in common use and 2500 miles possible if required.

Since it was established in 1945, WSMR has continuously updated and modernized ground instrumentation, telemetry, sensors, computers, and data collection/reduction/analysis techniques. The Physical Science Laboratory (PSL) of New Mexico State university has had a support contract with the Range since 1946. In the early 1960's it was recognized that capabilities had undergone enormous modernization and refinement, and that a handbook of procedures and methodologies would be of considerable assistance to data gathering and analysis personnel, as well as customers of the missile range. This resulted in, "The Handbook of Data Reduction Methods," printed in 1964.

The Handbook was the bible for those engaged in range data reduction and evaluation, but after 12 years it was again apparent that the book needed revision to reflect changing methodology, and expansion to include new technologies and capabilities. Thus, in July 1976 PSL was asked to perform the revision and update, a task that was to take 5 years. The new, 1600-page, ten-volume document, renamed "The Data Systems Manual," is a product of combining WSMR in-house capabilities with those available through the PSL contract. It includes new optical systems, and reduction and analysis procedures; extends documentation to all instrumentation data conversion and reduction systems that provide data to Range Users; standardizes mathematical notation and simplifies descriptions of processes used at WSMR; identifies existing deficiencies and recommends improvements.

Systems described in the set of volumes include Cinetheodolite, Telescope, Fixed Camera, Telemetry, Doppler Velocity & Positioning, Drone Formation Control, Laser Position Acquisition & Tracking. Detailed emphasis is given to pertinent theory and practice in the fields of statistics, least squares estimation, meteorology & atmospheric sciences, geodesy & coordinate transformations, operating principles of instrumentation systems, field operating procedures, data recording media and formats, actual data reduction procedures. All supporting documents used are referenced and identified. Although the task of writing the manual is considered complete at the present time, additional volumes will be added as new support technology and systems assume significant roles in National Range inventory.

Requests for the Data Systems Manual should be made through military channels to COMMANDER, WSMR ATTN: STEWS-NR, WSMR, NM 88002.

GENERAL DESCRIPTION

Data Systems Manual Format

The White Sands Missile Range Data Reduction Handbook has been completely revised, reorganized, expanded from one to ten volumes, and renamed the WSMR Data Systems Manual. This new set covers three types of material: General background and introduction, mathematical background material, and detailed discussions of the specific instrumentation systems and their associated data.

Introduction to the set as a whole is placed in a single volume, Data Products. It contains a general treatment of the subject, descriptive rather than mathematical, and a mathematical appendix. It also includes a Master Glossary of terms used in all ten volumes of the set. Each entry serves as an index pointing to the primary discussion location of the subject, in addition to providing the basic definition of the term. Each individual volume has its own glossary and thus can stand alone.

The mathematical background is contained in four volumes: Techniques of Statistical Analysis, Least Squares, Coordinate Systems, and Map Projections, and Meteorology and Timing. These include mathematical development of general techniques and specialized procedures related to the individual instrumentation systems volumes.

Individual instrumentation systems are covered separately in five volumes: Radar Systems, Telemetry Systems, the Drone Formation Control System, Optical Instrumentation Systems, and Optical Data Reduction. These include mathematics specific to each system, and descriptive material covering various instrumentation systems in use at WSMR.

This five-year updating project included all phases of technical publication preparation: research, development of mathematical models, writing, editing, graphics, photography, and word processing.

Data Products

This volume serves as an introduction to the entire manual. It provides an overview of the instrumentation systems available at WSMR, those which collect test data directly and those which are support systems. An extensive description of the Real-Time Data System is included. Detailed descriptions of the individual instrumentation systems are reserved for the appropriate instrumentation volumes and this overview directs the reader to whichever type of coverage is required in more detail.

A general informative description of coordinate systems is included to lay groundwork for a discussion of specific data products. It also directs attention to the more detailed mathematical material published elsewhere in the set.

The discussion of standard data products is primarily descriptive. These include trajectory parameters, attitude data, targeting parameters, and data computed using meteorological information. These are presented as representative of data products available at WSMR that do not require special programming. It is emphasized, however, that computations may be adapted for special applications and computational procedures may be developed for additional parameters, as required.

Most of these computations are treated in more mathematical detail in other volumes. This general discussion again serves as a roadmap to other applicable technical volumes. Parameters not covered in explicit detail elsewhere are handled in a special mathematical appendix to this volume.

The Master Glossary includes terms used in all volumes of the set, not just those exclusive to the Data Products volume. Each entry thus serves as an index to point to the location of the primary discussion of the subject. Each individual volume also has its own glossary to enable it to stand alone.

Techniques of Statistical Analysis

This volume serves as a source book for applied statistical analysis, providing a statistical background for Data Reduction procedures discussed in volumes covering specific instrumentation systems. It covers statistical distribution functions, estimation theory, planning and design of experiments, hypothesis testing, analysis of variance, and statistical error propagation.

In discussing distribution functions, emphasis is on use and selection of the appropriate function for specific applications. This includes use of the method of moments, the chi-square test, the Kilmogorov-Smirnov test, and the Shapiro-Wilk test. The section on estimation theory covers point estimation, interval estimation, and tolerance intervals. This discussion lays the groundwork for a detailed treatment of the Least Squares technique contained in a separate volume. Discussion of planning and design of experiments include choice of factors and response variables, process of defining the population and choosing a sample, and the selection of assumptions and subsequent development of models to assure flexibility of the final plan.

Hypothesis testing is covered in terms of the statement of hypotheses, definition of risks and types of errors, use of distribution-free statistics, the power of a test, and operating characteristics curves. Analysis of variance is divided into one-way and two-way models, with and without replication. This discussion includes multiple regression and related experimental designs as well as transformation of data for use of the Taylor expansion, variate difference method, and tests for outliers.

If material pertaining to derivations and proofs is not readily available in standard sources, more detailed discussions are included in the appendices to this volume for the user's convenience. The appendices also include some very common tables, as well as a few highly specialized tables not available in convenient published form.

Least Squares

This volume covers the specialized area of estimation theory known as the Least Squares technique. It includes a generalized introduction to the subject with the definition of the conditional equations as they relate to the estimation process.

Major topics include Least Squares point estimation, smoothing and numerical differentiation, sampling rates, and frequency domain data.

Least Squares point estimation covers weighting limitations, residual weighting process, constrained least squares process, experimental design in Least Squares point estimation, numerical analysis, estimators, and the Kalman filter technique.

Smoothing and numerical differentiation covers smoothing in the time domain, power series smoothing, moving arc smoothing, and the use of orthogonal polynomials. Sampling rates are considered as applied to both the time domain and the frequency domain. The subject of selection of sample rates and the consideration of misfit error is included.

The frequency domain is treated primarily in terms of Fourier series analysis, including transformation of both harmonic and nonharmonic data, power and spectral series analysis. Smoothing in the frequency domain is discusses with respect to the design of various filtering techniques.

Specialized Mathematical derivations which are not required for understanding material treated in the main text are included as appendices.

Coordinate Systems and Map Projections

This volume provides background theory and mathematical development of standard types of coordinate systems. The systems covered range from earth-based to object-oriented, and include both mathematical systems used only for computational convenience and systems used for presentation and analysis of test data. Conversion of data from one system to another is also included.

The earth-based systems provide the basis for most computations. This discussion covers both the natural coordinates used in field measurements and mathematical coordinates used for analysis of diverse data. The general types of mathematical systems treated are the ellipsoidal, geocentric, parametric, geodetic, and Cartesian coordinate systems. The object-based reference systems used for presentation and analysis of data are then developed as a special type of Cartesian system.

Mapping projections are treated separately, as a means of relating three-dimensional to two-dimentional space, as is required by the restrictions imposed in data presentation. Transformation of data from three-dimensional to two-dimensional space is covered, as is the reverse process for the case in which the projection parameters of the map are known. This also provides for the transformation of data from one mapping system to another. The mapping projections treated at length are the Lambert conformal, the Mercator, and the Transverse Mercator projections.

Conversion of coordinates between different three-dimensional systems is also included. The case of different Cartesian systems is treated at length, using both the method of successive rotations and the formation of a transformation matrix through use of direction cosines. A section is also included covering the use of series approximations for some of these conversions. Inertial coordinate systems are accorded special treatment.

Meteorology and Timing

This volume covers the derivation of mathematical models, development of standard models based on these mathematical assumptions, and their application to the analysis and correction of flight data for atmospheric conditions. It includes the effects of atmospheric refraction and attenuation, as well as measureable parameters such as temperature, pressure, relative humidity, and wind. It also covers the various types of time, such as solar, sidereal, and atomic, and describes the application of different timing systems for both definition of test data and synchronization of test data collection.

Meteorological background material is covered in terms of the standard reference atmospheres and accepted laws of meteorology. Computations of the various meteorlogical parameters are then derived. Examples are vapor pressures, density, index of refraction, virtual temperature, and dew point temperature.

The modelling of the effects of refraction is covered both theoretically and in terms of special cases: flat earth model, spherical model, and astronomical model. Attenuation is considered in terms of molecular and aerosol scattering and absorption, and the attenuation of electromagnetic energy in dust, haze, fog, clouds, and ice. Extensive tables of refraction and attenuation parameters are included in the appendices.

The correction of trajectory data for weather conditions is also a major subject. This discussion includes geometric, geopotential, pressure, and density altitudes, the set of general wind-corrected parameters, and the set of wind-corrected parameters associated with drag.

The section on time and timing systems covers the various types of astronomical time in detail, in terms of appropriate applications to point-in-time determination. The standard time forms, UT 0, UT 1, UT 2, and UTC, are included as well as the standard transmission codes used for data synchronization.

Radar Systems

This volume provides background material on the theory of radar instrumentation systems, with special attention devoted to application of radar as a measuring system. Two sytems in use at WSMR, FPS-16 and MPS-36, are treated in detail.

Background theory is presented covering the basic measurements that can be obtained using radar and the methods which may be used to convert these basic measurements into the metric data necessary for trajectory description and analysis. Procedures are given for the computation of corrections for systematic instrumentation errors such as mislevel, collimation, and miszeroing.

Hardware is discussed in terms of the configuration of a radar system, including tracking, orientation, and data subsystems. Data acquisition for the WSMR systems is treated in detail, including transmission and data formats.

Systematic error corrections are derived in general terms but applied to specific systems. Corrections for radar bias errors include those errors arising from axial misalignments: mislevel, collimation, and secondary axis error. Correction for bending moment, encoder eccentricity and index errors, servo lag errors and the effects of refraction is also discussed.

A special section is devoted to the subject of radar cross-sectional area data and its related parameters.

The total error to be expected in radar data is modelled in terms of the Geometric Dilution of Precision (GEDOP), and error contour curves are presented for typical cases.

Telemetry Systems

This volume contains a description of the capabilities, limitations, and data handling techniques of telemetry systems in general, with special emphasis on several specific systems in use at WSMR. It discusses the function and capabilities of subsystems involved in acquisition and processing of telemetry data associated with on and off range missions. Described in detail is the data handling and processing capabilities of the Telemetry Data Center.

Telemetry hardware, including transducers, signal processors, transmitters, receivers, and ground station equipment, is covered. General standards and characteristics of both frequency-division and time-division multiplexing systems are discussed. Special attention is given to the various modulation techniques: Pulse Amplitude, Pulse Position, Pulse Duration, and Pulse Code.

Recording and reproducing processes for data retrieval are also discussed, including various types of magnetic tape handling equipment.

The WSMR telemetry system is covered in terms of its various subsystems. Data acquisition subsystems include the Telemetry Acquisition Systems, the Transportable Telemetry Acquisition System, the Transportable Automatic Tracking System, the Telemetry Mobile Van, the Transportable Manual Tracking System, and the Telemetry Special Purpose Van.

Data transmission systems covered are the Telemetry Acquisition and Relay System, the Transportable Telemetry Acquisition and Relay System, and the Telemetry Data Relay System.

The data handling and processing systems are discussed in terms of display and processing subsystems available, and the capabilities of the Telemetry Data Center, including data processing.

Drone Formation Control System

The DFCS, and independent support instrumentation system, controls drones in flight in a variety of formation configurations and flight patterns. It uses a radio frequency link between ground station and transponder in the drone to measure slant range. This information is then used to perform position computations and produce control commands from a ground-based computer.

The material covers basic principles of system operation, capabilities and limitations. A mathematical appendix explains the equations used by the computer to perform its tracking and control functions.

Optical Instrumentation Systems

This volume contains a description of various optical instrumentation systems: Contraves Cinetheodolites, Askania Cinetheodolites, Versatile Tracking Mounts, Fixed Cameras, and Ballistic Cameras. Each such system is treated separately.

The Contraves Cinetheodolites are discussed in terms of their specifications and various subsystems. These include the shaft position measurement system, main optical system, camera system, angle data system, timing system, tracking system, and acquisition system. Configuration of the instrument site itself is also included. The Askania Cinetheodolite is covered in the same manner, plus a discussion of the Mobile Cinetheodolite Mount.

The Versatile Tracking Mount is covered in terms of its specifications, associated optical lenses, shaft position measurement system, acquisition and tracking system, station description and field site operation.

The Fixed Camera system is covered in terms of camera specifications, data systems, shutter assembly, and film drive assembly. Both 70mm and 35mm cameras are described.

Ballistic Cameras are also covered in terms of their specifications, optical systems, shutter assembly, and description of the instrumentation site.

Optical Data Reduction

This volume contains a mathematical development of procedures used in reducing data from optical instrumentation systems. It also includes background material and a general discussion of geometric optics as it applies to the handling of metric data.

The volume is separated into five sections: General Background, Cinetheodolites, Versatile Tracking Mounts, Fixed Cameras. Topics which apply to more than one type of instrument are covered in the section on general background theory, which also includes a detailed mathematical development of the position estimation process.

The treatment of each type of instrumentation includes digitization of the optical records, orientation process, and correction for errors.

The total error to be expected is examined in terms of the Geometric Dilution of Precision (GEDOP) and error contours are included to illustrate this point.

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14. Abstract

This report analyses the ten volumes (1600 pages) edited by the Physical Science Laboratory (PSL) of the New Mexico State University for The White Sands Missile Range (WSMR), entitled "The Data Systems Manual". The ten volumes are titled: Data products, Techniques of statistical analysis, Least squares, Coordinate systems and map projections, Meteorology and timing, Radar systems, Telemetry systems, Drone formation control system, Optical instrumentation systems, Optical data reduction.

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